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TITLE: QUANTUM GRAVITY AND NEW FORCES

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Quantum Gravity and New Forces

by

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Abstract

The quantum-gravity-inspired phenomenology for gravitational forces is described. New gravitational phenomena, qualitatively similar to those attributed to the so-called "fifth-force" are to be expected. The parameters of a model with these features have been constrained by the geophysical tests of the inverse-square law of Stacey, et al. This model is then able to explain the apparent discrepancies between the recent results of Thieberger and of Adelberger and collaborators. A striking new prediction of the model is that antiprotons should experience a substantially larger gravitational acceleration than normal matter. Gravitational red-shift experiments are also proposed as tests for the new forces.

In 1979 the late Joel Scherk noted that, generically, modern quantum gravity theories contain partner fields of the graviton [1] which will induce the types of phenomena which later were attributed by some to a new "fifth-force".

Specifically, a violation of the inverse-square law of gravitation and a composition-dependence of the acceleration due to gravity are to be expected. The ingredients of these theories which are capable of producing macroscopic classical "gravitational" forces are the spin-two graviton, and spin-one and spin-zero fields, which Scherk called the graviphoton and graviscalar, respectively.

The graviton is massless and coupled to the energy-momentum tensor. In the linearized classical limit it produces the inverse-square, composition-independent, Newtonian gravitational force. In contrast, the graviphoton and graviscalar are expected to be massive, so that in the same limit they produce Yukawa-type violations of the inverse-square law. Moreover, they will in general give composition-dependent forces. This is because the graviphoton should couple to some conserved current, such as baryon number and the graviscalar can couple to (electromagnetic) binding energy differently than to quark masses, so that it too can yield a force on neutral atoms which varies with baryon number rather than total energy. One could expect, for symmetry reasons, that the coupling strengths of graviphoton and graviscalar to matter could be approximately equal and of gravitational size. The repulsive graviphoton force on matter in the earth's field would then be approximately cancelled by the attractive graviscalar force. [2,3]

The only question then is whether the ranges of the two new fields are long enough to lead to measurable effects in gravitational measurements. Assuming for the moment that they are, we are led to a two-component scenario for the new gravitational force phenomena, and a linearized potential between two point masses m_1, m_2 of

$$V(r) = -\frac{G m_1 m_2}{r} \cdot \left[1 - a e^{r/v} + b e^{-r/s}\right] \qquad (1)$$

where a, b (v,s) are the graviphoton and graviscalar coupling (ranges) respectively. In particular we have argued that

$$a, b \sim \left(\frac{B}{\mu}\right)_1 \left(\frac{B}{\mu}\right)_2 \qquad (2)$$

From earth surface/LAGEOS satellite gravity comparisons we have

$$|bs - av| \lesssim 14\,m \tag{3}$$

under the assumption s, v $\ll R_{\oplus}$ just as $|\alpha\lambda| \lesssim 14\,m$ in single-component scenarios.

To obtain more restrictive constraints on b, a, v, s Stacey et al. have fitted their geophysical data to the potential (1) under the assumption $b \approx a = 1$. They find [4]

$$\begin{gathered} a - b \approx 0.01 \quad for \quad 10m < v < 4 \times 10^5 m \\ s \approx \left\{ \begin{array}{cc} v \;, & v \sim 10\,m \\ 1.01v, & v \sim 10^5 m \end{array} \right\} \end{gathered} \tag{4}$$

and

$$bs - av \approx \left\{ \begin{array}{cc} -10^{-2} v \;, & v \sim 10m \\ -10^{-4} v \;, & v \sim 10^5 m \end{array} \right\} \tag{5}$$

which is clearly consistent with their single Yukawa fit in terms of the extra contribution to the gravitational acceleration

$$\Delta g = 2\pi G\rho(bs - av) \tag{6}$$

from the two new forces, at the surface of the earth.

The possibility of such large ranges ($>10^5$ m) severely complicates the interpretation of recent composition-dependent tests of gravity, which are only sensitive to horizontal components of a new force. Specifically, to generate a significant horizontal component one needs a site where there is a big density contrast over distances comparable to the large ranges, associated with geological/topographical features. In our recent paper with Ander, [5] we have argued that this could be the explanation of the apparent disagreement between the results of Adelberger et al. [6] and Thieberger. [7]

In view of such difficulties of interpretation, what then would be a definitive test of this scenario? Clearly, experiments to detect a composition-dependence of the vertical component of gravitational acceleration could avoid such problems. But substitution of the allowed ranges indicate that on ordinary matter, acceleration differences of order μ Gal are to be expected, and we have seen at this conference the difficulty of such measurements. [8] Note, however, how this changes if we compare the gravitational acceleration of antimatter with matter. For antiprotons a is now negative (opposites attract) and we could have $\bar{p}$'s falling with an acceleration greater than for ordinary matter by as much as

$$(bs + av) \approx 100\,Gal \qquad (7)$$

i.e., 10 % greater. [9]

An experiment capable of testing the gravitational acceleration difference of $\bar{p}$'s and H^- ions to 1% precision has been approved by CERN (PS 200). [10]

A totally different class of experiments which should be done focus on the scalar force alone. Simple scalars couple to the trace of the energy-momentum tensor, T^μ_μ, leading to an extra (composition-independent) contribution to the gravitational red-shift. The graviscalar, however, can also couple to the electromagnetic binding energy through the quantity $F_{\mu\nu}F^{\mu\nu}$. This new coupling would lead to a composition-dependence of the gravitational red-shift. We suggest, therefore, that high-precision tests of the gravitational red-shift with a variety of different materials can provide a new window on possible new gravitational forces.

Finally, we would like to remark on a rather careless use of terminology in recent fifth-force discussions. Many people have referred to a "fifth-force" coupling to, I_3, the third-component of strong isospin. However, from the Eötvös-type experiments on neutral matter this cannot be distinguished from a coupling to (B-2L). We note, however, that a vector field coupled to (B-2L) has no effect on meson weak decays, whereas, one coupled to I_3 does. We find, that with the range and coupling strengths given by Boynton et al. [11], that a vector field coupled to I_3 is disallowed [12] as it would violate the experimental bound on the branching ratio of the decay

$$K^+ \rightarrow \pi^+ + (\text{unobserved neutral}) \qquad (8)$$

This example shows the effective role which conventional particle physics can play in a field which is sometimes regarded as merely gravitational.

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